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Metal Levels In Sediment Samples Collected Under Salmon Aquaculture Net Pens In The Bay Of Fundy, New Brunswick

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Atlantic Region
Environment Canada
16th Floor, Queen Square
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Metal Levels In Sediment Samples Collected under Salmon Aquaculture Net Pens in the Bay of Fundy, New Brunswick

By:

W. R. Parker[1] and J. G. Aubé[2]

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1. Environment Canada, Environmental Protection Branch
Fredericton, New Brunswick
2. Environment Canada, Environmental Conservation Service
Moncton, New Brunswick

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Abstract

Concerns about possible chemical residues in the sediments that accumulate under salmon net pens prompted Environment Canada to conduct a series of studies to collect samples of these sediments and analyze these samples for a suite of chemical contaminants. The initial survey was conducted in 1998 and the results provided some indication that copper, zinc and cadmium were elevated at some salmon farm sites. In 1999, a follow up survey of 10 salmon farms was conducted. These results clearly indicated a consistent pattern of elevated copper in sediments collected under salmon net pens. The results also indicated that cadmium was not elevated. Unfortunately, no results for zinc were obtained due to analytical problems. In 2000 and 2001, 8 locations on one farm site were sampled and the sediments were analyzed for metal concentrations. A similar pattern of elevated copper was again observed. As well, there was continued evidence that zinc was elevated above background concentrations in the sediments collected directly under the farm sites. Although the sources of these elevated metal concentrations are not fully understood, there is some evidence to indicate that the use of copper-based antifouling coatings on the net pens could release copper. Some salmon food formulations can contain zinc and /or copper which are added as essential minerals in the fish's diet.

Key Words salmon farm, sediments, metals, copper, zinc

Résumé

Pour donner suite aux inquiétudes suscitées par la présence possible de résidus chimiques dans les sédiments qui s'accumulent sous les parcs en filet pour la salmoniculture, Environnement Canada a effectué une série d'études dans le cadre de laquelle on a prélevé des échantillons de sédiments afin d'en analyser la teneur en une série de contaminants chimiques. L'analyse des premiers échantillons, prélevés en 1998, a montré que les concentrations de cuivre, de zinc et de cadmium pouvaient être élevées dans certaines stations de salmoniculture. En 1999, une étude de suivi effectuée dans dix stations a clairement mis en évidence une tendance constante à la présence de fortes concentrations de cuivre dans les sédiments prélevés sous les parcs en filet. Les concentrations de cadmium, par contre, étaient peu élevées; malheureusement, à cause de problèmes d'analyse, on n'a pu obtenir aucun résultat pour le zinc. En 2000 et 2001, on a prélevé dans 8 emplacements d'une même station des échantillons de sédiments dont on a analysé la teneur en métaux; encore une fois, on a relevé une tendance similaire à de fortes concentrations de cuivre. La teneur en zinc des sédiments prélevés directement sous les stations de salmoniculture était également toujours supérieure aux concentrations naturelles. Bien que l'on ne sache pas trop d'où viennent ces fortes concentrations de métaux, des données indiquent que les revêtements antisalissure à base de cuivre utilisés sur les parcs en filet pourraient libérer du cuivre. Certaines formules alimentaires données aux saumons peuvent aussi contenir du zinc ou du cuivre, qui sont ajoutés comme minéraux essentiels au régime alimentaire des poissons.

Mots clés salmoniculture, sédiments, métaux, cuivre, zinc

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Introduction and Background

The growing of Atlantic salmon in marine net pens in the Bay of Fundy began in the 1970's and the industry has continued to expand since that time. In 1999, there were approximately 80 salmon farms in the Bay of Fundy, primarily in southwest New Brunswick. These farms produced nearly 20,000 metric tonnes of fresh Atlantic salmon annually with a value of about $150 million (Janowicz and Ross, 2001). The farms operate under licenses issued by the New Brunswick government. These licenses establish where a salmon farm can be located, the number of fish that can be grown on a site and the monitoring and reporting requirements for the farm operators.

Fine-grain organic sediments tend to accumulate under the salmon net pens on a farm site. These wastes consist primarily of fish feces, uneaten food pellets and marine algae cleaned from the net pens. The amount of deposition that occurs is dependent on several factors - water depth, water current, the number of fish on the farm, the feeding practices used on the site and net cleaning practices. Generally, salmon farms located in deeper water with stronger tidal currents have less sediment accumulation while farms located in shallower areas or areas with lower current velocities experience greater waste build up. In addition to the smothering effects of this deposition of fine organic material, the waste material also can consume oxygen from the over lying and the interstitial waters as it decomposes due to its high organic carbon content (Wildish et al, 1999). At sites with the heaviest build up of organic waste, the sediments under the net pens become anoxic (devoid of oxygen) and are unable to support benthic organisms. Due to the anaerobic conditions, the sediments can generate elevated concentrations of hydrogen sulphide and ammonia.

Each salmon growing operation is required by its provincial license to conduct an annual survey of the quality of the marine sediments under the net pens. The monitoring program includes a visual inspection of the benthic habitat under the net pens by a SCUBA diver and a video recording of the conditions. The oxidation/reduction potential (Redox) and total sulphide content of the sediments are measured and samples are collected for total volatile solids measurements (Anon., 1995; Wildish et al., 1999). A rating system has been developed to classify each salmon farm site according to the condition of the marine sediments under the net pens. An "A" rating is given to a site that is having minimal impact on sediment quality. A "B" rating is assigned to a site where the sediment conditions are somewhat impacted but are still acceptable. A "C" rating indicates that the marine sediments are heavily impacted and the benthic habitat conditions are unacceptable and require remediation.

In addition to the stresses on the benthic habitat caused by anoxia and smothering, there have been concerns raised about the possibility that the sediments could contain residues of contaminants. These contaminants could originate from the pesticides used to treat the fish for sea lice infestations, anti-fouling treatments used on the net pen structures, food

additives that become contaminants from uneaten fish food and other chemicals used in fish husbandry. In 1998, Environment Canada and the Department of Fisheries and Oceans conducted a joint study to look for the presence of environmental contaminants in sediments under salmon farms (Burridge, et al, 1999). That study collected sediment samples from four salmon farm sites that were measured for metals, pesticides and toxicity. The results indicated that sediments from some of the sites sampled had elevated concentrations of copper and zinc. As well, the cadmium results were highly variable and appeared to be elevated at the "C" rated sites. Pesticide residues, chlorophenols and polychlorinated biphenyls (PCBs) were not detected in any of the samples and levels of polycyclic aromatic hydrocarbons (PAHs) were all below CCME guideline levels.

As a follow-up to the 1998 results, in the fall of 1999, Environment Canada conducted a study to determine metal concentrations in sediments from under salmon farm sites. The main objectives of the 1999 study were to evaluate the apparent variability of metal concentrations in the sediments and to look specifically at the concentrations of copper, zinc and cadmium to confirm if the elevated levels measured in the 1998 samples accurately reflected the conditions around the salmon net pens. Sediments from ten salmon farms were sampled and analyzed for metal concentrations.

As a component of a more intensive sediment survey at one salmon farm site in 2000 and 2001, two sets of sediment samples for metal analyses were collected from eight locations under one salmon farm. An additional five control sites located in a 100 metres radius from the salmon farm were also sampled.

Methods

Field Sampling Methods

In 1999, the field crew made the selection of the sites. The locations of the sites remain unknown to all parties with the exception of the field crew. A total of 10 sites representing a range of seafloor characteristics were visited. At each location, the samples were collected using a diver operated grab sampler ($0.1 m^2$). Each sample was retrieved from the seafloor and placed in sealed 500 ml polyethylene bags. Samples were frozen and stored until transported to the Environment Canada Environmental Quality Laboratory in Moncton.

For the intensive survey, two temporal sets of sediment samples were collected by SCUBA divers from the same eight locations under the one salmon farm site, the first in September 2000 and the second in May 2001. For the May 2001 survey, five additional sediment samples were collected about 100 metres out from the perimeter of the farm to provide background information. The divers descended to the bottom at each sampling location and collected two core tubes of sediment for the chemical analyses. The divers

using their depth gauges determined the depth for each sampling location. The core tubes used were clear Plexiglas, 7 cm in diameter and 60 cm in length. The tubes were equipped with plugs in both ends. The divers slowly inserted the tubes into the sediment using a gentle twisting motion to minimize disturbance of the sediment. The tubes were sealed at the top, slowly extracted from the sediment bed and then sealed at the bottom. The tubes were placed in a net bag and brought to the surface. The cores were handed to the boat crew who inspected the cores to ensure that there was sufficient sample and that the core tubes were properly sealed and were not leaking. The tubes were stored in a vertical position until the sub-sampling in order to minimize disturbance of the contents. To obtain the samples for metal analyses, the core tube was opened at the top and the water layer was carefully decanted off. The top 20 cm of sediment was removed from the core and placed in a polyethylene mixing bowl. This material was thoroughly mixed by hand using a disposable spatula and the homogenized mixture was sub-sampled into the appropriate containers. The containers were labeled and placed in a cooler for transport to the laboratory.

Sample Locations

For the 1999 survey, at each site, a gradient of sample locations was established in the direction of the predominant current and the greatest sediment deposition from a cage. A total of 4 samples were collected at each site commencing under the centre of the cage and then at 15 meters, 30 meters and 45 meters down gradient from cage center. The farm sampled included six (6) "C" rated sites and four (4) "B" rated sites (based on 1998 environmental monitoring program assessments). For quality assurance purposes, four (4) blind replicate samples, representing 10 % of total number of samples, were collected at random. Each replicate was coded QA #1-#4 and the field crew recorded which samples were duplicated.

For the 2000 and 2001 samples, the same eight locations under one salmon farm were sampled. A geographical reference for each sampling location was determined using a hand held Global Positioning System (GPS). This allowed the survey team to return to the same approximate location to collect the samples in May, 2001. For the 2000 samples, blind duplicate samples were collected from 2 of the 8 sampling locations for quality assurance purposes. In the spring of 2001, one blind duplicate sample was collected.

Analytical Methods

For each year of sampling, samples were analyzed at the Environmental Quality Laboratory (EQL) for a suite of metals such as cadmium (Cd), cobalt (Co), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn).

In the laboratory, samples were homogenized to ensure representative analysis of the individual discrete samples. For the samples received by the laboratory in 1999, a 10 g aliquot of the homogenous sediment was taken and dried overnight at a temperature of 100+/- 3 °C. This sample was then pulverized to a fine powder using a mortar and pestle, and transferred to a secondary sample container to await digestion. A 0.5 g (500 mg) dry aliquot of the samples was extracted of their non-residual metals using an acid digestion with "aqua regia". This extraction involved mixing a 12mL solution of hydrochloric acid and nitric acid, in the ratio of 3:1 respectively, to the dried sediment, and slowly heating the mixture at approximately 80°C (USEPA, 1986). Continuous heat was applied until sample volume was reduced to roughly 0.5 mL without bringing to dryness. The sample was then further extracted with an additional 12 mL volume of aqua regia and reduced one last time. The extract was then diluted to 50mL, by first adding 10 mL volume of 0.2% nitric acid to the beaker, to re-dissolve some of the metals, and then quantitatively transferred in a 50 mL volumetric flask. The volume was made up to the mark with the same 0.2 % nitric acid solution. Samples were left overnight to settle and the supernatant analyzed.

For the 2000 and 2001 sample analysis, the EQL used a newly acquired methodology for the extraction of the metals from the sediment; an extraction using microwave assisted processes (MAP). The microwave technology permits the same type of extraction as the "aqua regia" extraction with faster and more efficient extraction of the metals from the sediments while using less acids. By using this new technology for metal extraction before analysis, zinc results could now be obtained.

Sample analysis of the extract required further preparation before introducing them to the Inductively Coupled Plasma - Mass Spectrometer (ICP-MS). This high capacity, multi-element instrument requires the addition of internal standards for quantification of the unknowns. First, the samples were diluted 10 fold prior to spiking. This was done to reduce the loading of the total dissolved solids onto the detector of the ICP-MS. Afterward, all the discrete and quality control samples were spiked at the same level with a solution of rare earth elements used as internal standards. These internal standards are used to help the analyst identify potential matrix effect that might interfere in the determination of the concentration of a certain element of interest. They also aid in the quantification of the elements in prolonged analysis in respect of the instrument's sensitivity and baseline drifting.

The concentration of the requested elements was determined in each extract. The calculation was then further progressed to determine the concentration of each element in the initial dry sediment. Many quality control samples were used to monitor and establish assurance in the method used on the discrete samples. A certified reference material (CRM SS-1) was used in the method to establish accuracy and efficiency. The reference material SS-1 is a "Type B naturally contaminated soil (not spiked or fortified) with a particle size of ~200 mesh" (SCP Sciences, 1997).

Data Analyses

The analytical results were received from the laboratory and were reported as micrograms per gram (ug/g) metal concentration dry weight. The data were entered into spreadsheets and from the spreadsheets, data were summarized into tables and analyzed for trends, patterns and differences using a variety of statistical tests (e.g. regressions analyses, correlation coefficients, tests for significant differences). As well, the results of this survey were compared to environmental quality guidelines and metal results from other sediment surveys.

Results

1999 Samples

A total of 44 samples were collected from 10 salmon farm sites in 1999; 4 samples from each site along the gradient and 4 blind replicate samples for quality control. The results of the metal analyses completed on these samples are summarized in Table 1 and presented in their entirety in Appendix Table A1. Cadmium concentrations were very low ranging from 0.12 µg/g to 0.94 µg/g. The median concentration was 0.29 µg/g. Cobalt was detected in all samples with a median concentration of 12.34 µg/g. The copper results were highly variable with values ranging from 12.89 µg/g to 115.72 µg/g; the median value was 21.95 µg/g. Lead had a median value of 25.80 µg/g and nickel had a median value of 31.10 µg/g.

Table 1 - Summary of the results of metal analyses on samples of sediment collected under salmon net pens in the Bay of Fundy in the fall of 1999.

Parameter	Cadmium µg/g	Cobalt µg/g	Copper µg/g	Lead µg/g	Nickel µg/g
Number of Samples	40	40	40	40	40
Mean	0.35	12.09	31.52	26.71	31.47
Median	0.29	12.34	21.95	25.80	31.10
Minimum	0.12	7.29	12.89	16.36	18.32
Maximum	0.94	15.23	115.72	52.02	45.48
Standard Error	0.03	0.32	3.35	0.96	0.85
Standard Deviation	0.04	2.00	21.21	6.04	5.37

2000 - 2001 Samples

A total of 24 samples were collected over the two sampling events. In the fall of 2000, samples were collected from 8 locations on the salmon farm plus 2 blind replicate samples were taken. In the spring of 2001, those same 8 locations were sampled plus 5 control sites located about 100 metres beyond the perimeter of the farm in southern, western and northern directions. One blind replicate was collected as well.

The results of the analyses on the 2000 and 2001 samples are summarized in Tables 2, 3 and 4. The full data are provided in Appendix Tables A2, A3 and A4. In the 2000 samples, cadmium, cobalt, lead and nickel concentrations were quite consistent over the site. Copper varied over a range from 20.7 µg/g to 111.3 µg/g and zinc concentrations ranged from 108.2 µg/g to 151.7 µg/g. In the spring of 2001, the samples from under the fish farm had similar values for cobalt. The cadmium values were all below detection limits. The detection limits for these samples were slightly higher than for the 2000 samples as a result of the different sample digestion method used. Therefore, direct comparisons of the two studies could not be made. The lead and nickel results were more varied over the site then in the fall samples with lead showing some higher values in the spring while the nickel concentrations were lower. Copper was highly variable with a range of values from 16.0 µg/g to 191.0 µg/g. The zinc values were also variable with a range from 75.5 µg/g to 354.0 µg/g. The sediment samples from the reference areas indicated that the 5 reference areas were similar in metal content for the metals measured. The reference sites reported comparable levels of cadmium, cobalt, lead and nickel to the levels measured in the sediments directly beneath the salmon net pens. However, copper and zinc values were lower and more consistent than the values observed in the under farm sediments.

Table 2 - Summary of metal results for sediment samples collected from randomly selected blocks under a salmon farm site on September 20, 2000. Results are reported as ug/g dry weight.

Summary Parameter	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
# of Samples	8	8	8	8	8	8
Mean	0.2	12.6	41.8	32.4	28.1	124.9
Median	0.2	12.6	35.0	32.5	28.2	122.9
Minimum	0.2	12.1	20.7	31.1	26.9	108.2
Maximum	0.4	12.9	111.3	33.5	29.2	151.7
Standard Error	0.0	0.1	10.3	0.2	0.2	4.7
Standard Deviation	0.1	0.2	29.1	0.7	0.7	14.7

Table 3- Summary of metal results for sediment samples collected from randomly selected blocks under a salmon farm site on May 16, 2001. Results are reported as ug/g dry weight.

Summary Parameter	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
# of Samples	8	6	8	8	8	8
Mean	< 0.7	12.3	61.6	33.2	22.4	205.6
Median	< 0.6	12.7	38.1	33.1	23.4	255.0
Minimum	< 0.5	9.1	16.0	25.2	13.8	75.2
Maximum	< 1.2	13.8	191.0	40.1	25.7	354.0
Standard Error	0.1	0.5	20.4	1.4	1.3	33.5
Standard Deviation	0.2	1.4	61.2	4.2	3.8	100.4

Table 4 - Summary of metal results for the reference sediment samples collected near a salmon farm site on May 16, 2001. All values reported as µg/g dry weight.

Summary Parameter	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
# of Samples	5	5	5	5	5	5
Mean	< 0.5	13.1	22.8	33.5	27.4	99.0
Median	< 0.5	13.0	23.5	33.3	27.8	98.5
Minimum	< 0.5	12.6	19.2	32.7	26.1	87.0
Maximum	< 0.5	13.6	24.6	34.6	28.0	108.0
Standard Error	0.0	0.2	1.0	0.4	0.4	3.5
Standard Deviation	0.0	0.4	2.2	0.8	0.8	7.8

Quality Assurance Results

1999 Samples

The results of the analyses of the certified reference material are presented in Appendix Table A5. All of the analyses fell within plus or minus (+/-) 15 % of the reference values which indicated very good efficiencies, minimal contamination and very low loss due to volatilization during heating and/or manipulation. Furthermore, reagent blanks showed very low and even undetectable contamination due to reagents or the glassware. The recoveries of the spiked elements confirmed low loss, if any.

Replicate samples and reference materials were also used to demonstrate if there was any variability in the method. Having all target elements fall well below 10% relative percent difference (RPD) indicates a well controlled method, good reproducibility, as well as good homogeneity in the samples from the initial point of extraction.

The seventh element requested for analysis was zinc. No results were reported for this element in the 1999 study, because of interference detected in ICP-MS analysis of the extract. Hydrochloric acid used in the aqua regia method is never completely eliminated from the extract in the volume reduction step of the procedure. The presence of high concentration of the chloride ion (Cl^-) creates many polyatomic species that interfere at the same atomic mass of zinc. This causes false positive at the zinc ion mass and makes it very difficult to accurately quantify the element of interest. Using the MAP technology permits the use of a minimal quantity of hydrochloric acid, which eliminates the matrix interference at those zinc isotope masses.

The majority of the field replicate samples showed good comparison but there were a couple of anomalies. Appendix Table A6 shows the percent difference between the original sample and the blind replicate. All of the duplicate samples for cobalt, nickel and lead had less than 15 % difference between replicates. One of the replicate samples for copper (Location 5B) had a 36 % difference between the two samples while the other three duplicate samples were within 15 % difference. The variability between the cadmium duplicate samples was quite high ranging from 10% to 73 %. However, the cadmium concentrations in these duplicate samples were all quite low (less than 0.6 µg/g) and near the detection limit of 0.1 µg/g. It is not unusual to experience higher variability when dealing with lower concentrations that are near the method detection limit. Appendix Figures A1 to A4 show the comparison of the replicate samples for 4 of the metals measured.

2000 - 2001 Samples

Comparison of the blind replicate samples to the primary samples is provided in Appendix Table A6. There was good agreement between the samples for cobalt, lead, nickel and zinc. One of the cadmium replicate samples was 33 % different but the values were just above the detection limit. One of the copper results from the 2001 survey was completely different from its replicate (38.1 µg/g compared to 191 µg/g or a 375 % difference). Tracking back through the analytical procedure of this duplicate indicated that this was in fact a real variability in the sample for this element. The same sample core was homogenized vigorously in the field and then split as a blind field replicate. Through data quality assurance protocols, this field duplicate indicated very low variability for all other metals analyzed.

Discussion

Relationship of Metal Concentrations with Distance from Net Pens

The 1999 samples were collected along a gradient from the centre of the fish cage outward to 45 metres. In general, the net pens were 70 metre polar circles with a diameter of 22 metres. To determine if there was a relationship between distance from the centre of the cage to the concentration of metal, correlation coefficients were calculated (Table 5). A correlation coefficient larger that 0.5 indicates that there is some relationship between the two variables and values closer to 1.0 indicate strong relationship between the variables. A negative correlation coefficient indicates that the variables are inversely related (i.e. as one variable increases, the other is decreasing). If metal contamination were originating from the salmon cage, one would expect to see a strong negative correlation between metal concentrations and distance from the centre of the cage toward the edges (i.e. metal concentrations decrease as one moves away from the net pen). There was no clear pattern like that for this data set. Another hypothesis could be that the main sediment deposition area from the salmon farm is not directly under the farm but located down gradient with the prevailing currents. That could explain some of the inverse correlations. For each metal, there were correlation coefficients between metal concentration and distance but these were negative at some sites and positive at others. As well, many of the sample locations did not have a strong correlation between metal concentration and distance. These observations are graphically represented by three-dimensional figures A5 to A9 in the Appendix. Although there were some obvious trends in the data, no consistent pattern of a relationship between concentration and distance emerged.

Table 5 - Correlation coefficients for sediment metal concentrations and distance from the centre of the fish cage.

Location #	Cadmium	Cobalt	Copper	Lead	Nickel
1	0.866	0.926	- 0.778	-0.766	-0.819
2	0.057	0.400	- 0.530	-0.580	0.451
3	- 0.986	-0.932	-0.318	-0.895	0.919
4	0.540	0.379	0.312	0.426	- 0.195
5	0.948	0.253	0.555	-0.079	-0.825
6	0.777	-0.567	0.778	-0.778	0.282
7	0.713	-0.390	0.941	0.295	0.170
8	0.987	-0.691	0.083	-0.553	0.611
9	- 0.299	-0.938	- 0.764	-0.949	-0.543
10	0.320	-0.867	0.243	0.747	0.785

CCME Sediment Quality Guidelines

The Canadian Council of Ministers of the Environment (CCME) has published environmental quality guidelines for marine sediments (CCME, 1999). However, guidelines have not been recommended for all of the metals measured in this study; no Canadian guidelines exist for cobalt and nickel. Table 6 summarizes the applicable CCME guidelines for metals in marine sediments and compares those guideline values to the values observed in this study. The guidelines have two values, an Interim Sediment Quality Guideline (ISQG) which serves as a warning level where concentrations greater than the guideline value have the potential to be harmful to aquatic organisms. As well, the guidelines propose a Probable Effects Level (PEL), concentrations at which harmful effects to aquatic organisms are likely to occur.

For the 1999 results, the median cadmium and lead concentrations in sediments from the 10 salmon farm sites did not exceed the interim sediment quality guideline nor the probable effect level. On the other hand, the median copper concentration exceeded the ISQG for copper. Of the 40 samples collected, 28 (87.5 %) had copper concentrations above the ISQG level of 18.7 µg/g. One sample exceeded the PEL concentration of 108 µg/g. Only one of the salmon farms sampled (# 2) had sediment copper values below the ISQG.

The results of the intensive survey at the one salmon farm site in 2000 and 2001 indicated that cadmium was never detected above the CCME ISQG, and lead exceeded the CCME ISQG in both sets of samples by only a slight margin (less than 10 % above guideline). Copper concentrations in both sets of sediment samples were approximately two times the ISQG. All but one of the sixteen samples exceeded the guideline value of 18.7 µg/g of copper. All of the reference samples, collected about 100 metres from the farm site, also exceeded the CCME ISQG for copper, but again only by a slight amount ranging from 2 % to 32 % above the guideline.

Table 6 - Comparison of CCME marine interim sediment quality guidelines to metal concentrations measured in sediments collected from some Bay of Fundy salmon farms.

Metal	CCME ISQG ug/g	1999 Samples Exceeding ISQG (n=40)	2000 Samples Exceeding ISQG (N=8)	2001 Samples Exceeding ISQG (N=8)
Cadmium	0.7	5 %	0 %	0 %
Copper	18.7	70 %	100 %	87.5 %
Lead	30.2	15 %	0 %	0 %
Zinc	124	n/a	50 %	62.5 %

Canadian Environmental Protection Act Limits

The Ocean Disposal Regulations of the Canadian Environmental Protection Act (CEPA) specify maximum concentrations within the waste for certain parameters that cannot be exceeded to allow the material to be disposed in the ocean. For the 5 metals that were measured in this study, only cadmium has a specified limit: 0.6 µg/g. The median concentration of cadmium in the 40 samples was 0.29 µg/g, which was half of the CEPA limit. However, 5 of the 40 samples (12.5 %) had cadmium concentrations that exceeded the CEPA limit. These 5 samples were spread among 3 of the sample sites (# 3, #5 and #8).

For sediment to be approved for ocean disposal, the median value of the cadmium must not exceed the limit (Environment Canada, 1995). For the intensive study at one salmon farm conducted in 2000 and 2001, the mean cadmium concentrations were also below the ocean disposal limit of 0.6 µg/g. Based on the observations in this study, it would be unlikely that ocean disposal of these sediments would be disallowed due to the cadmium concentrations.

Comparison to Background Metals in Sediment

Several other recent studies have looked at metal concentrations in sediments from the northwest Bay of Fundy. Table 7 summarizes the results of these studies and compares their results to those of this study.

Table 7 - Mean metal concentrations in sediments samples from recent studies conducted in the northwest Bay of Fundy. All measurements reported as µg/g.

Metal	Loring 1996	Burridge Et al 1999	Bugden 1999	Parker & Aubé 1999	Parker & Aubé 2000	Parker & Aubé 2001[1]	Parker & Aubé 2001[2]
Cadmium	0.07	0.3	0.14	0.35	0.24	< 1.0	< 0.5
Cobalt	11	n/a	15.2	12.09	12.6	12.3	13.1
Copper	14	25.6	19	31.52	41.8	61.6	22.8
Lead	28	24.3	24.9	26.71	28.14	22.4	27.4
Nickel	28	n/a	38.2	31.47	32.4	33.2	33.5
Zinc	78	118.1	94.6	n/a	124.87	205.6	99.0

1 sediments from under salmon farm only
2 sediments from reference areas only

The concentrations of cobalt, lead and nickel are similar for the five sets of sediment samples. Cobalt and nickel are slightly higher in Bugden's study. The cadmium concentrations are very low but are highest in the samples taken directly under the salmon cages.

The copper values measured in sediments directly under the salmon pens exceeded the copper levels measured in the 1996 survey of a similar area of the Bay of Fundy (Loring et al, 1998). That study reported mean copper concentrations of 14 µg/g for a series of 19 samples collected from Passamaquoddy Bay and 14 samples collected in the St. Croix River estuary. The sample locations were not close to salmon farm sites. In Bugden's 1999 study, which included 58 sediment samples, collected in the Letang Estuary and Passamaquoddy Bay, the mean total copper concentration was 19 µg/g. Bugden's samples were collected in areas near salmon farms but not directly under nor adjacent to farm sites.

The mean concentrations of copper in sediments from under the net pens in the 2000 and 2001 surveys were higher than the levels in the reference areas. The copper concentrations in the fall of 2000 samples were statistically higher in the under cage sediments compared to the reference sites ($P = 0.01$). In the spring of 2001 samples from under the net pens, there was a wide variation in copper results and these results were not

statistically different (P = 0.284) from the reference areas (Figure 1). Zinc concentrations in the under cage sediments were elevated and like copper values, surpass background levels. The mean zinc concentrations in the sediments in Loring's study, Bugden's study and from the reference sites used in the 2001 survey were all less than 100 µg/g. The mean zinc concentrations of the sediments from under the net pens were 125 µg/g in 2000 and 206 µg/g in 2001. The zinc concentrations in the under cage sediments collected in the fall of 2000 were statistically higher than the reference site sediments (P = 0.003). The results of the under cage sediments from the spring of 2001 showed a wide degree of variation and as a result were not statistically different (P = 0.127) from the reference areas (Figure 2).

Relationship to Site Rating

In 1999, 10 sets of sediment samples were collected for this study at "B" and "C" rated farm sites. There was some indication in an earlier study (Burridge et al, 1999) that the more degraded sites had higher metal concentrations. The copper results for the four "B" sites were compared to the copper results for the six "C" sites. There was no significant difference between the copper concentrations for the two groups (p = 0.751). Therefore there was no indication that copper levels were higher at the more degraded sites.

Potential Sources of Metals

The results of this study clearly indicated a pattern of elevated copper concentrations in the sediments directly beneath the salmon farm sites. This pattern of elevated copper in sediments near marine salmon farms has been observed in other locations as well, not only on the Canadian east coast. A recent study (Brooks, 2001) on Canada's west coast reported that the mean copper concentration in sediments from near salmon farms using copper based antifouling coatings was 48.24 µg/g. The author compared these values to results from sediments under salmon net pens that did not use copper based antifouling coatings which had a mean copper concentration of 26.27 µg/g and a reference area distant from any salmon farms where the mean copper concentration was 12.01 µg/g. The author suggested that with the elevated organic carbon of the sediments under the fish pens, the elevated copper concentrations should not be toxic to marine animals but that this would need to be confirmed.

Figure 1 - Copper in Sediments Collected From Under a Salmon Farm

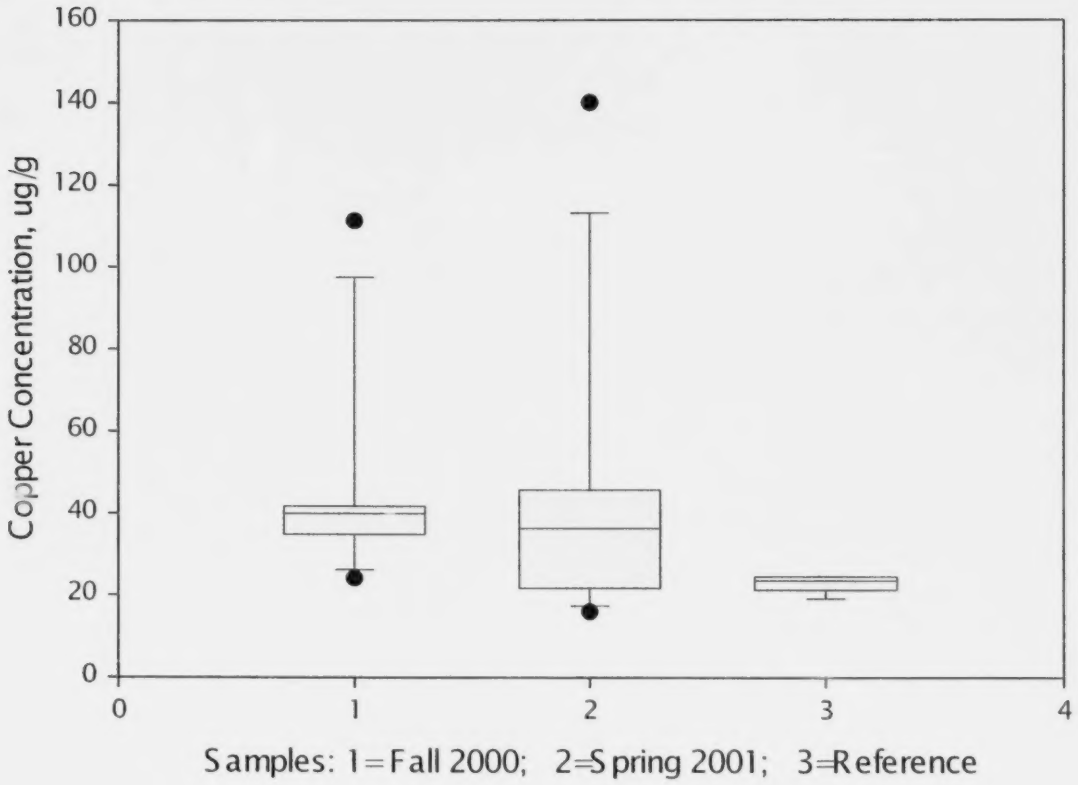
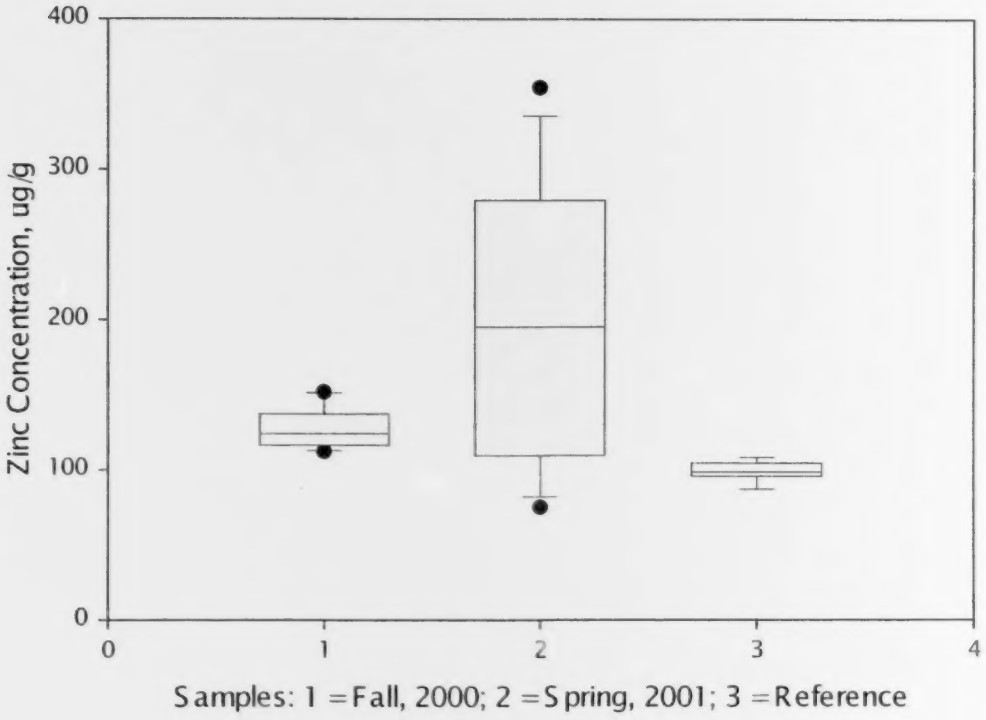


Figure 2 - Zinc Concentrations in Sediments Collected From Under a Salmon Farm



The Norwegian government identified concerns with the use of copper based antifouling compounds on salmon net pens and established an objective to substantially reduce copper releases by the year 2010 (Anon., 1999). They also report (Anon., 2000) that no progress towards achieving that objective was accomplished in 1999 and the sale of copper based antifouling compounds was similar to the 1998 level.

The most likely source of the copper in the sediments is the copper-based antifouling coatings that are used on the salmon farm net pens. The nets are dipped in a copper rich solution before being installed on the farm. Copper does leach from the nets, albeit at a slow rate. Copper that does leach from the net pens would have very low solubility in salt water and would settle out as a precipitate. Copper-based antifouling coatings are also used on commercial fishing boats, aquaculture service boats and recreational boats. The leaching of copper from these vessels may contribute to the build up of copper in the sediments around salmon farms. The food fed to farm raised salmon contains copper as an essential mineral for the fish. It is also possible that uneaten food, containing copper, may also contribute to the concentrations observed in the sediments around the salmon farms.

Conclusions

1. Copper was elevated at most marine salmon farm sites surveyed and exceeded the CCME Interim Sediment Quality Guidelines in 80% of samples and at 9 of 10 sites. Three samples had copper levels that exceeded the CCME Probable Effects Level.

2. Nickel, cobalt and lead were found at background concentrations and do not appear to be of any immediate environmental concern.

3. Although there were a few elevated cadmium results, there was no apparent relationship with the site ratings. Therefore, elevated cadmium concentrations should not create an obstacle to obtaining an ocean disposal permit for sediments from below net pens, but it would be necessary that cadmium be measured on a site-specific basis to obtain the required permit.

4. Zinc results were not obtained from the 1999 study due to analytical problems. The 2000 and 2001 data for zinc indicated that the concentrations were elevated at that one site. The mean zinc concentration in the 2000 samples was equal to the CCME Interim Sediment Quality Guideline and the mean zinc concentration in the 2001 samples was almost double the CCME ISQG but still less than the CCME Probable Effects Level (PEL).

Recommendations

1. Sediment toxicity studies should be conducted to determine if the observed elevated concentrations of copper in sediments under salmon aquaculture net pens could have any adverse effects on aquatic organisms.

2. Further studies are required to determine the sources of the observed elevated copper observed under salmon net pens. The relative contribution of copper from each potential source should be determined.

3. A temporal study of the metal sediment loading at aquaculture sites could be an effective way of determining how the copper and other metals are accumulating. The under cage sediments at some sites continue accumulating layer upon layer under the net pens, so the analyses for metals in the different layers of core samples could be indicative of how the metals were accumulating in the sediments over time.

4. As the 1999 study was unsuccessful at measuring zinc in sediments, further monitoring should be conducted to confirm indications of elevated concentrations of zinc in sediments under salmon aquaculture net pens.

5. There is conflicting information about the relationship between site sediment rating and metal concentrations. The 1998 study (Burridge et al, 1999) found some evidence of higher metals at "C" rated sites while this 1999 study did not observe the same pattern. The 1999 study did not include any "A" rated sites. Additional surveys of metal content in sediments from sites representing all rating could help address this question.

Acknowledgments

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Appendix

Appendix Table A1 - Results of metal analyses on samples of sediment collected under salmon net pens in the Bay of Fundy in the fall of 1999.

Farm Site	Site Rating	Distance from cage centre	Cadmium µg/g	Cobalt µg/g	Copper µg/g	Lead µg/g	Nickel µg/g
1	C	45	0.14	12.37	25.36	25.42	29.82
1	C	30	0.15	12.71	18.71	26.61	29.36
1	C	15	0.15	13.15	17.61	20.51	30.21
1	C	0	0.20	13.10	18.56	21.67	31.11
2	C	45	0.13	11.64	17.43	24.26	29.23
2	C	30	0.14	12.73	17.93	25.86	31.73
2	C	15	0.17	8.01	12.89	17.11	20.98
2	C	0	0.13	11.12	16.01	21.44	27.46
3	C	45	0.72	13.88	45.14	35.75	34.59
3	C	30	0.67	14.06	34.57	38.08	35.30
3	C	15	0.54	12.09	42.89	29.08	30.26
3	C	0	0.42	10.94	38.52	22.68	27.67
4	B	45	0.22	11.42	21.71	23.74	28.38
4	B	30	0.18	13.91	21.84	27.29	33.86
4	B	15	0.33	12.09	30.77	26.72	28.72
4	B	0	0.26	13.09	22.29	25.65	31.38
5	B	45	0.45	12.49	38.77	25.75	32.51
5	B	30	0.57	12.12	47.02	25.03	33.20
5	B	15	0.57	12.38	39.58	27.55	32.82
5	B	0	0.69	12.30	48.36	24.65	34.63
6	B	45	0.12	13.95	20.33	28.62	33.59
6	B	30	0.19	13.38	21.73	28.34	32.97
6	B	15	0.14	14.56	20.75	28.58	36.62
6	B	0	0.33	11.87	82.24	23.74	30.55

Appendix Table A1 - continued

Farm Site	Site Rating	Distance from cage Centre, m	Cadmium µg/g	Cobalt µg/g	Copper µg/g	Lead µg/g	Nickel µg/g
7	C	45	0.16	12.70	20.20	23.12	33.62
7	C	30	0.48	14.16	22.06	24.93	36.94
7	C	15	0.21	14.52	30.72	31.24	39.60
7	C	0	0.74	10.93	46.90	23.84	31.09
8	C	45	0.25	14.17	29.21	29.94	40.12
8	C	30	0.40	15.04	115.72	32.58	43.01
8	C	15	0.62	15.23	81.17	34.30	45.48
8	C	0	0.94	7.75	48.87	20.74	24.04
9	C	45	0.42	11.08	22.22	26.03	29.05
9	C	30	0.32	9.67	18.11	24.48	24.72
9	C	15	0.44	9.63	20.95	22.32	25.85
9	C	0	0.33	7.29	14.62	16.36	35.39
10	B	45	0.23	11.64	16.68	27.12	27.64
10	B	30	0.31	12.10	18.38	29.13	30.27
10	B	15	0.26	10.63	14.89	25.98	26.77
10	B	0	0.27	7.70	19.01	52.02	18.32
5	QA#1	30	0.51	12.82	30.31	25.84	32.08
7	QA#2	30	0.13	14.92	18.48	22.07	37.08
9	QA#3	15	0.36	9.32	24.17	23.47	22.15
10	QA#4	15	0.19	10.46	14.32	23.65	22.69
Mean			0.35	12.09	31.52	26.71	31.47
Median			0.29	12.34	21.95	25.80	31.10
Minimum			0.12	7.29	12.89	16.36	18.32
Maximum			0.94	15.23	115.72	52.02	45.48
Standard Error			0.03	0.32	3.35	0.96	0.85
Standard Deviation			0.04	2.00	21.21	6.04	5.37

Appendix Table A2 - Metal results for sediment samples collected under a salmon farm site on September 20, 2000. Sample blocks are randomly selected locations within the farm perimeter. Duplicate samples are designated with an "a". All values reported as µg/g.

Sample Block	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
5	0.4	12.6	42.3	28.3	32.3	151.7
10	0.2	12.9	111.3	29.2	33.3	124.0
18	0.2	12.7	24.1	28.6	32.6	112.1
18a	0.2	12.6	20.7	28.0	32.6	108.2
19	0.2	12.6	CO	27.4	32.2	113.8
21	0.2	12.1	34.6	26.9	31.1	149.9
24	0.3	12.6	35.4	28.5	33.5	124.2
25	0.3	12.6	39.9	28.1	31.7	123.8
25a	0.2	12.5	26.0	27.7	31.8	122.0
36	0.2	12.7	CO	28.7	32.9	119.0
Mean	0.2	12.6	41.8	32.4	28.1	124.9
Median	0.2	12.6	35.0	32.5	28.2	122.9
Minimum	0.2	12.1	20.7	31.1	26.9	108.2
Maximum	0.4	12.9	111.3	33.5	29.2	151.7
SE	0.0	0.1	10.3	0.2	0.2	4.7
SD	0.1	0.2	29.1	0.7	0.7	14.7

Appendix Table A3 - Metal results for sediment samples collected under a salmon farm site on May 16, 2001. Sample blocks are randomly selected locations within the farm perimeter. All values reported as µg/g.

Sample Block	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
5	< 0.9	13.8	140	23.6	37.2	291
10	< 0.5	12.7	20.5	25.6	40.1	120
18	< 0.8	11.5	38.1	20.6	30.7	267
18a	< 0.8	12.4	191	22.9	32.6	255
19	< 0.6	12.4	16	20.2	31.2	75.2
21	< 0.5	12.9	22.8	25.7	33.1	98.3
24	< 0.6	12.9	34.5	23.4	34.4	128
25	< 1.2	9.1	50.5	13.8	25.2	354
36	< 0.6	13.1	40.9	25.4	34.1	262
Mean	< 0.7	12.3	61.6	33.2	22.4	205.6
Median	< 0.6	12.7	38.1	33.1	23.4	255.0
Minimum	< 0.5	9.1	16.0	25.2	13.8	75.2
Maximum	< 1.2	13.8	191.0	40.1	25.7	354.0
SE	0.1	0.5	20.4	1.4	1.3	33.5
SD	0.2	1.4	61.2	4.2	3.8	100.4

Appendix Table A4 - Metal results for the reference sediment samples collected near a salmon farm site on May 16, 2001. All values reported as µg/g.

Sample Block	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
Control 1	< 0.5	12.8	22	27.3	32.8	98.5
Control 2	< 0.5	13.5	24.6	28	33.9	108
Control 3	< 0.5	13.6	23.5	27.9	34.6	103
Control 4	< 0.5	13.0	24.5	27.8	33.3	98.4
Control 5	< 0.5	12.6	19.2	26.1	32.7	87
Mean	< 0.5	13.1	22.8	33.5	27.4	99.0
Median	< 0.5	13.0	23.5	33.3	27.8	98.5
Minimum	< 0.5	12.6	19.2	32.7	26.1	87.0
Maximum	< 0.5	13.6	24.6	34.6	28.0	108.0
SE	0.0	0.2	1.0	0.4	0.4	3.5
SD	0.0	0.4	2.2	0.8	0.8	7.8

Appendix Table A5 - Laboratory quality control data for metal analyses on the 1999 sediment samples

Sample		Cadmium µg/g	Cobalt µg/g	Chromium µg/g	Copper µg/g	Lead µg/g	Nickel µg/g
Sample A	Mean	0.15	12.5	32.1	18.7	26.4	28.9
Sample B	Mean	0.15	12.9	33.6	18.7	26.8	29.8
	Method Mean	0.15	12.7	32.8	18.7	26.6	29.4
	Method SD	0.0	0.28	1.06	0.0	0.28	0.64
	RSD	0 %	2.23 %	3.23 %	0 %	1.06 %	2.16 %
CRM SS-1	Method Mean	35.6	31.8	59.7	652	214	249
	Method SD	0.25	2.19	4.08	20.1	6.39	12.0
	RSD	0.71 %	6.91 %	6.84 %	3.09 %	3.00 %	4.84 %
	Theoretical	34	28. 0	64.0	690	233	231
	%recoveries	105%	114%	93.3%	94.5%	91.8%	108%
Reagent Blank #1	Conc. Mean	1.06	<0.1	<0.1	<0.1	8.11	<0.1
Reagent Blank #2 spiked	Conc. Mean	116	598	931	396	837	220
	Theoretical	114.2	628	1042	386	858	222
	% recoveries	101%	95.2 %	89.3 %	102 %	96.6 %	99.1 %

Appendix Table A6 - Percent difference between replicate samples of sediment samples collected from salmon farm sites in the Bay of Fundy

Year of Survey	Sample Location	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
1999	5B	10.0%	5.8 %	35.5%	3.3%	3.4 %	n/a
1999	7B	72.5%	5.4 %	16.2%	11.5%	0.4 %	n/a
1999	9C	18.7%	3.2 %	15.4%	5.2%	14.3 %	n/a
1999	10C	24.4%	1.6 %	3.8%	9.0%	15.2 %	n/a
2000	18	0 %	0.8 %	14.1 %	2.1 %	0 %	3.5 %
2000	25	33.3 %	0.8 %	34.5 %	1.4 %	0.3 %	1.6 %
2001	18	0 %	7.8 %	375.1 %	11.2 %	6.2 %	4.5 %

Figure A1 - Comparison of replicate samples for cobalt in sediment

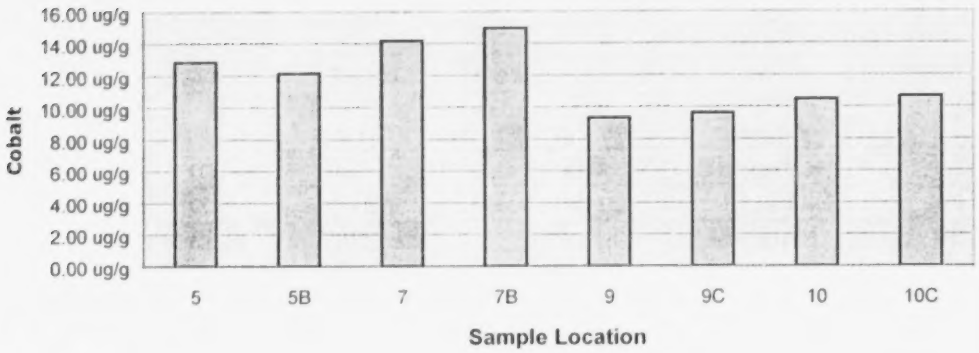

Figure A2 - Comparison of replicate samples for cadmium in sediment

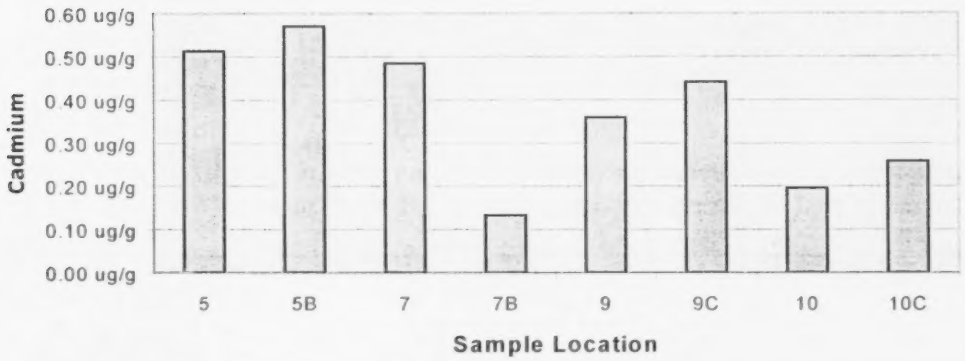

Figure A3 - Comparison of replicate samples for nickel in sediment

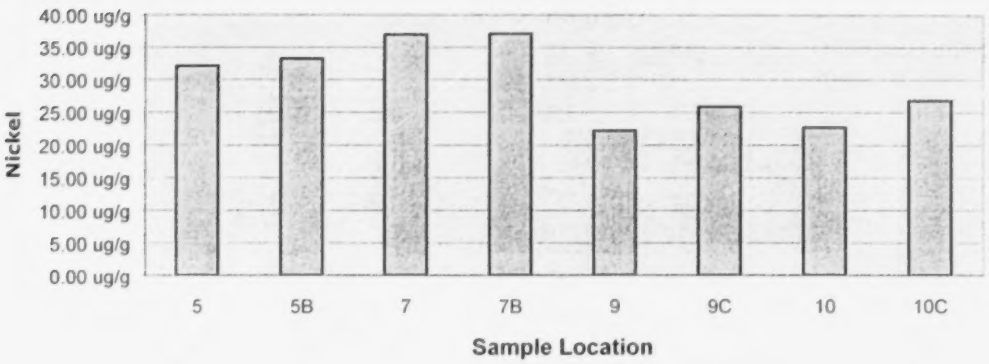

Figure A4 - Comparison of replicate samples for copper in sediment

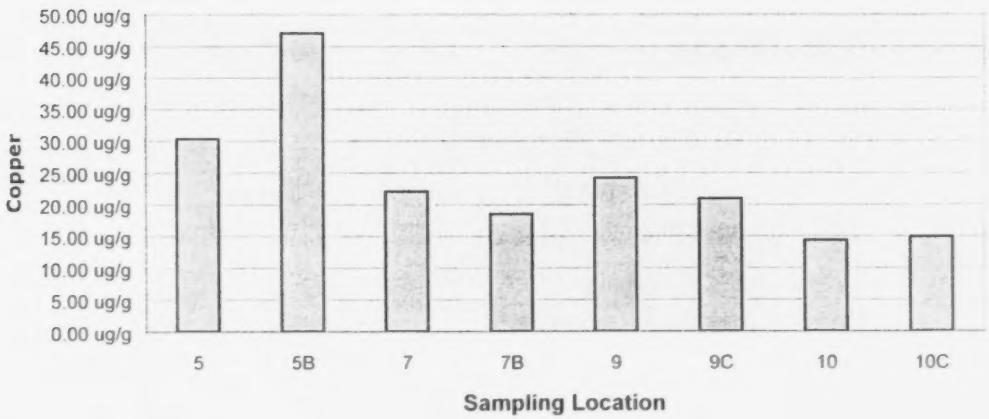

Figure A5 – Cadmium in sediments collected under ten salmon farms in 1999.

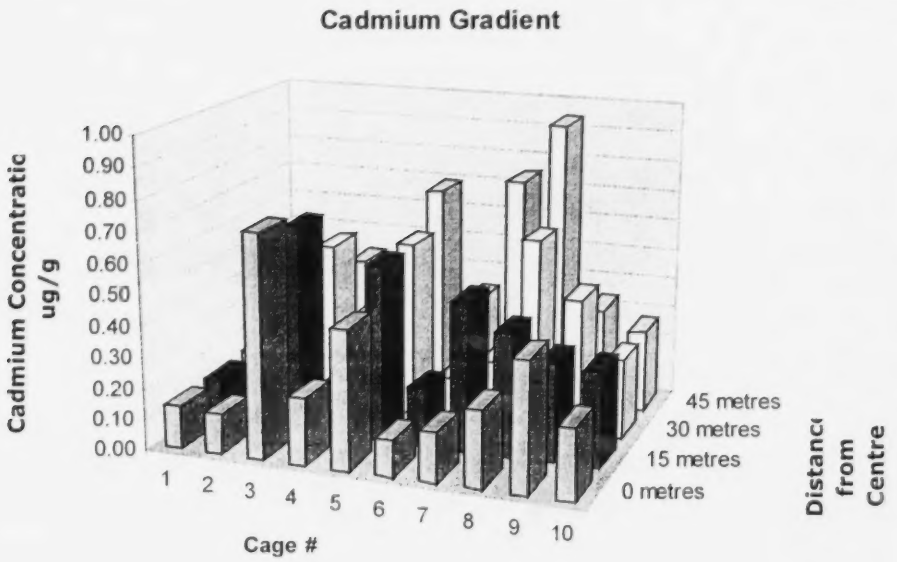

Figure A6 – Cobalt in sediments collected under ten salmon farms in 1999.

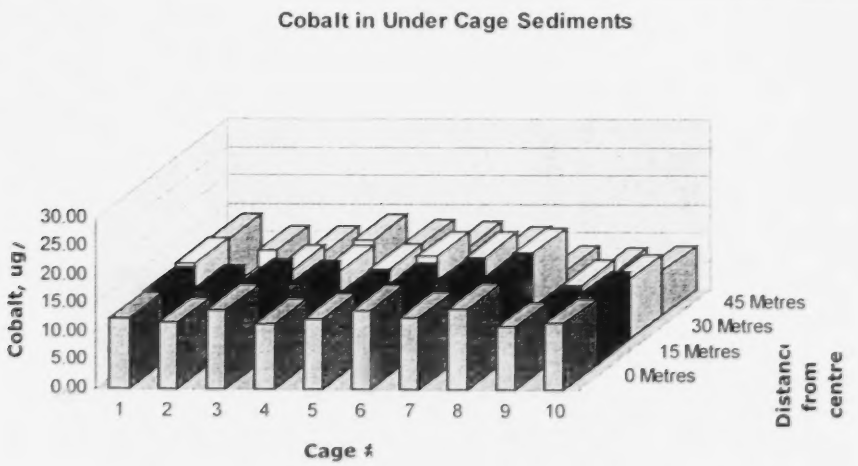

Figure A7 – Copper in sediments collected under ten salmon farms in 1999.

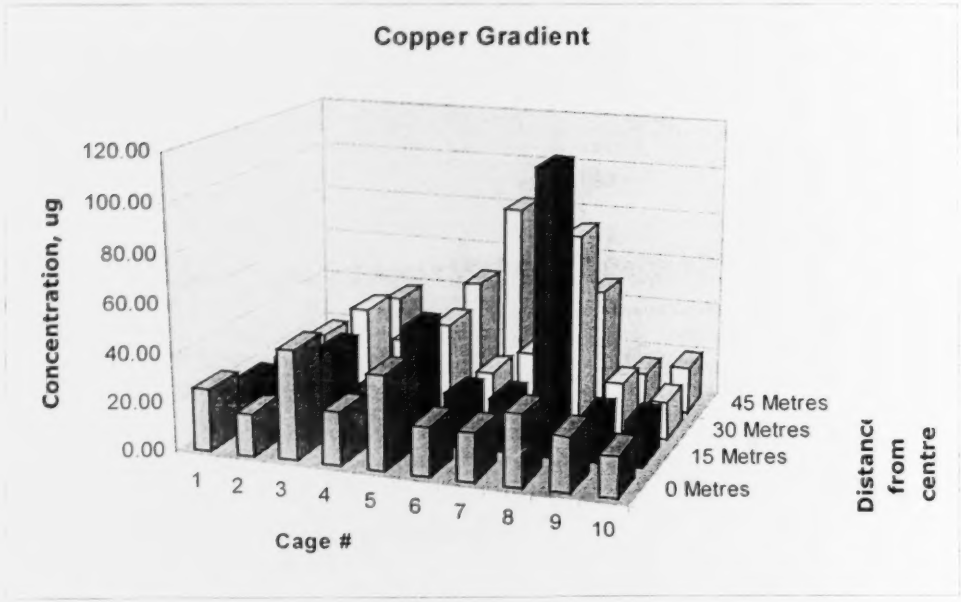

Figure A8 – Lead in sediments collected under ten salmon farms in 1999.

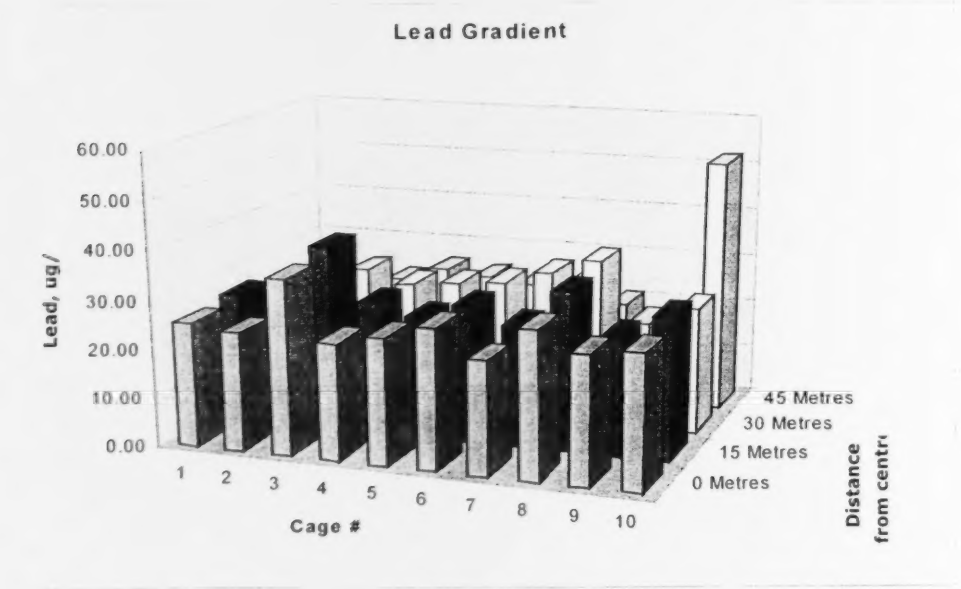

Figure A9 – Nickel in sediments collected under ten salmon farms in 1999.